SEMICONDUCTOR DEVICE FOR DETECTING ELECTROMAGNETIC RADIATION OR PARTICLES

This is a continuation of application Ser. No. 737,628, filed June 22, 1985, now abandoned.

The present invention relates to a semiconductor device for detecting electromagnetic radiation or particles, the device comprising a semi-insulating substrate, a first layer of either n-type or p-type conductivity deposited thereon, a plurality of layers of alternating conductivity types deposited in series on said first layer, a strongly p-type electrode region which extends through said p-type and n-type layers and defines a first selective electrode, and a strongly n-type electrode region which also extends through said p-type and n-type layers, and which is spaced apart from said strongly p-type region and defines a second selective electrode.

Semiconductor devices of this kind, often referred to as doping superlattices, are known from German patent specification No. 22 61 527.

It is known that these semiconductor devices have unusual electrical and optical characteristics.

The object underlying the present invention is to provide an improved semiconductor device which is suitable for detecting radiation, in particular radiation with energies less than the bulk semiconductor band gap energy (e_g^o) in the host material, and which is also suitable for detecting particles with equivalent energies, with the device preferably having a relatively low capacitance and a relatively low dark current at room temperature.

In order to satisfy this object there is provided, in accordance with the invention, a device of the initially named kind which is characterised in that the device is a homogeneous semiconductor in which the n-type and p-type layers other than the first layer and the outermost layer have substantially identical thicknesses and doping concentrations; in that the first layer and the outermost layer are of the same conductivity type and have a thickness substantially equal to one half of the thickness of each of the other layers; in that the first layer and the outermost layer have a doping concentration substantially identical to the doping concentration of the other layers; and in that the total number of layers of alternating conductivity is an odd number; whereby a high reverse bias can be applied to the device, thereby tilting the resultant electric field with respect to the layers.

It has been found that semiconductor devices characterised as above are extremely sensitive to infrared radiation, exhibit a low dark current at room temperature and have very low capacitance and therefore fast response.

These devices, which are formed by periodic alternate doping with n- and p-type impurities in an otherwise homogeneous material, have been grown by molecular beam epitaxy (MBE). The space charge induced periodic modulation of the energy bands in these doping superlattices leads to a confinement of electrons and holes in alternate layers ("indirect gap in real space") and to an effective energy gap that can be tailored between zero and the bulk semiconductor band gap energy E_g^o in the host material by appropriate choice of the doping concentrations (N_d, N_a) and thicknesses (d_n, d_p) of the constituent layers. Due to the effective spatial separation recombination of excess carriers is strongly reduced, and large deviations of electron and hole concentrations from thermal equilibrium become quasi-stable. This non-equilibrium excited state is characterised by separate quasi-Fermi levels E_{fn} for electrons and E_{fp} for holes. The charge of mobile excess carriers, however, partly compensates the bare impurity space-charge potential resulting in a reduction of the original potential amplitude V_o. Consequently, the free carrier concentration as well as the effective energy gap are no longer constant material parameters in a given doping superlattice, but they are tunable by external carrier injection or extraction.

The internal space-charge fields in doping superlattices result in a strong exponential tail of the absorption coefficient α (ω) at photoenergies below E_g^o (Franz-Keldysh effect). The absorption of photons with energy $E_g^{eff} < h\omega < E_g^o$ is thus possible. In addition, the absorption coefficient is tunable, since for a given photon energy the overlap between initial and final states changes with variation of the effective gap (or quasi-Fermi level difference $E_{fn} - E_{fp}$). These peculiarities make doping superlattices very attractive for application in optical detectors covering a large energy range.

In general, the constituent superlattice layers are not completely depleted at zero bias and the undepleted central portions of the n-type and p-type layers are at the same potential as the selective n- and p-type electrodes.

In one development of the invention the semiconductor device is characterised by its combination with circuit means for applying a high reverse bias across the selective electrodes.

This embodiment allows the energy sensitivity to be selected. For some applications, the reverse bias is preferably selected to be so high that the capacitance of the device is determined only by the electrode geometry. In this case the capacitance of the device becomes very low and its speed of response is accordingly high. Furthermore the device can be caused to avalanche thus enhancing the signal.

In a further embodiment means is provided for varying the reverse bias which enables the energy sensitivity of the device to be tuned.

When the reverse bias is applied between the n-type and p-type layers via the selective electrodes electrons and holes are extracted from the central portions of the respective layers and the amplitude of the space charge potential increases. If the reverse bias is further increased, the n-type and p-type layers of the superlattice are finally totally depleted at a certain threshold voltage and the corresponding potential wells for carrier confinement have reached their maximum depths. At this point, the strongly enhanced internal space-charge fields make possible the absorption of extremely long wavelength radiation through the Franz-Keldysh effect. Further increase of the reverse bias only adds a constant electric field parallel to the length of the layers (i.e. the potential is tilted in the layer direction), and the photogenerated electrons and holes are more efficiently swept out into the selective electrodes to be detected by photoconductive response.

In the above described semiconductor devices the total number of layers of alternating conductivity types is typically an odd number lying between 9 and 51 and preferably amounting to 21, the device should have a minimum total thickness of one micron.

By increasing the number of layers one obtains increased sensitivity, the effort required to produce a very